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(56) Documents cited
GB 2162445 A   GB 2102311 A   GB 2102310 A
WO 88/03841 A1   WO 86/01130 A1   US 4683061 A
US 4544486 A

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(54) Hydrocyclone

(57) A hydrocyclone separator for separating oil from water includes a first portion (10) with a central overflow outlet (12) and at least one tangential flow inlet (14), an essentially single angled conical second portion (16), and a substantially cylindrical third portion (18), with a central underflow outlet (20). The separator is characterised by specified parametric relationships between the lengths and internal dimensions of the various portions and outlets. The first portion is preferably cylindrical; but need not exist as an entity separate from the conical portion (16) which may thus double up as the inlet portion.
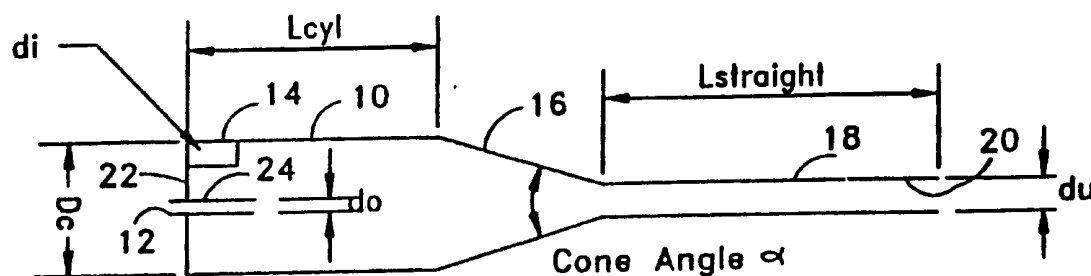
Hydrocyclone Dimensions
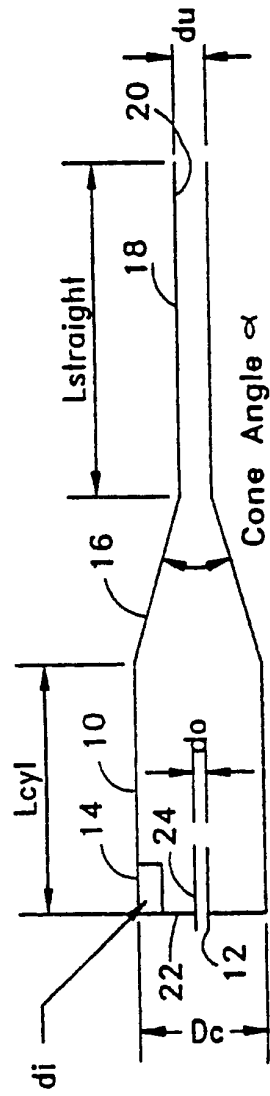

FIG.1

GB 2 230 210 A

Hydrocyclone Dimensions

FIG.1

Cone Performance vs. Inlet Size and Cone Throughput
Dc=3.0 Pu=75 Leyl/Dc=1 lt./Dc=18 vfl/Dc=1.0 Theta=6
Bumpass Crude Median Size 25 microns
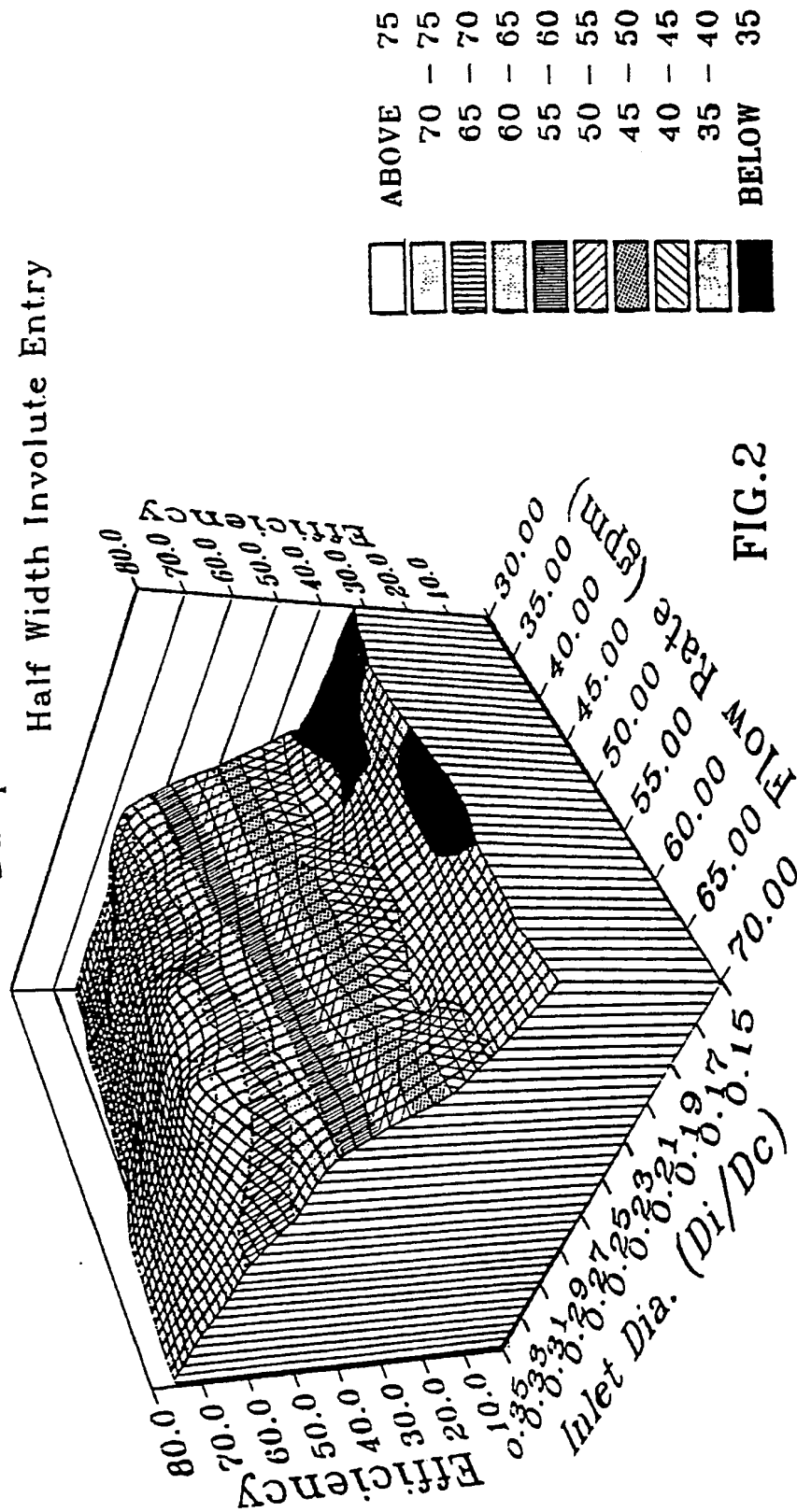Half Width Involute Entry

ABOVE   75
70 — 75
65 — 70
60 — 65
55 — 60
50 — 55
45 — 50
40 — 45
35 — 40
BELOW   35

FIG.2

Effect of Flow Rate on Separation
Dc=3.0 di/Dc=.25 do=.078 du/Dc=.33 lcyl/Dc=2 lu/Dc=12

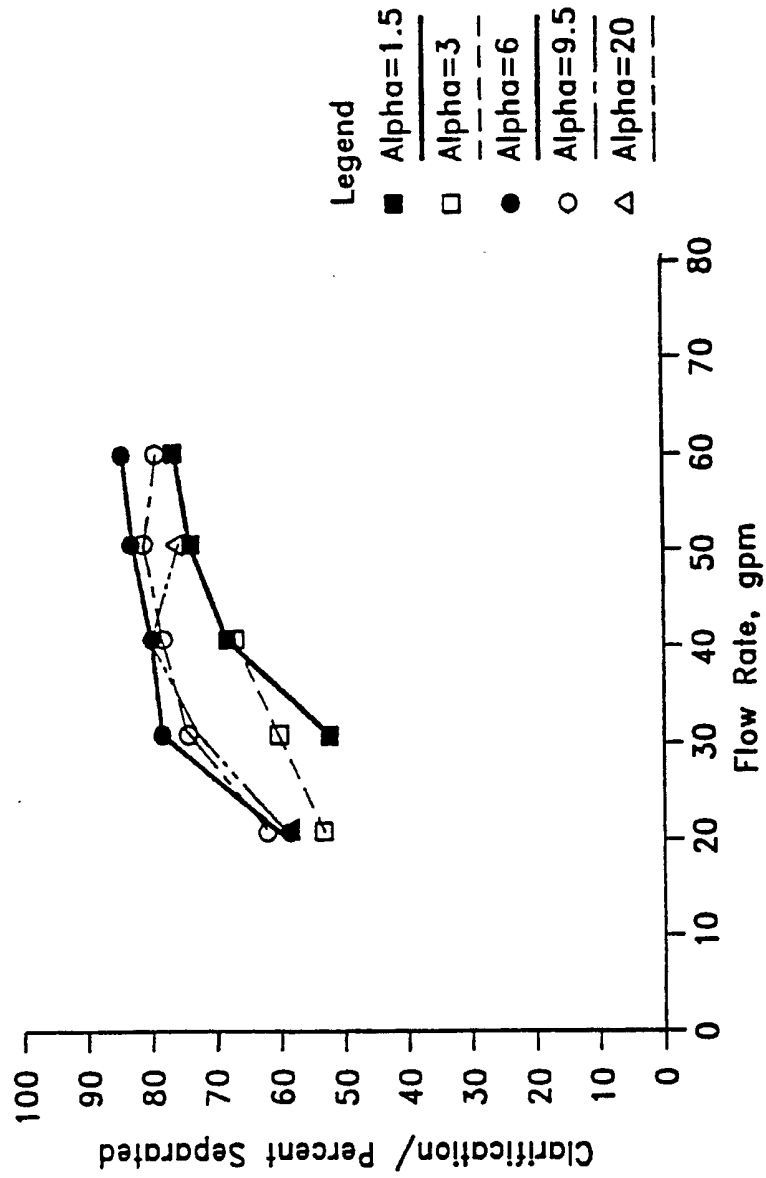FIG.3

Effect of Underflow Size on Separation
Twentyfive median Micron Feed Slurry
Dc=3.0 di/Dc=.25 do=.078 lu/Dc=12 lcyl/Dc=2 alpha=6

Legend
■ du/Dc=.25
■ du/Dc=.33
● du/Dc=.42
○ du/Dc=.50

Clarification/ Percent Separated

Flow Rate, gpm

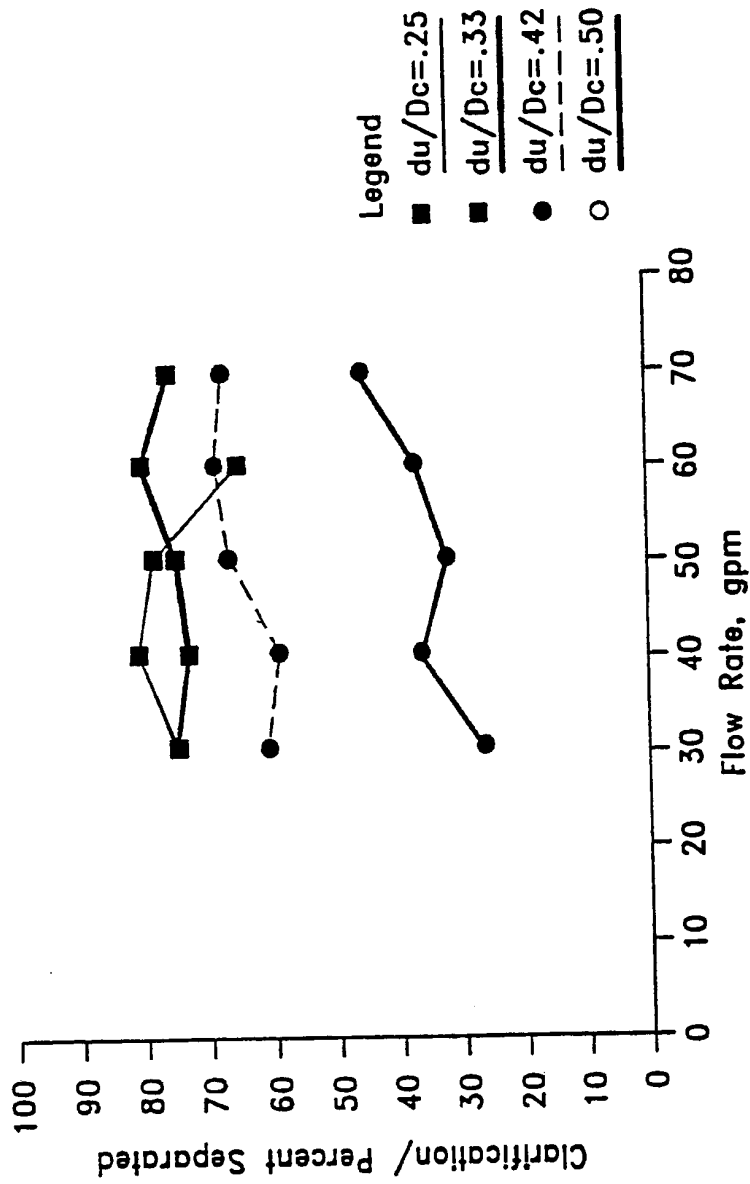FIG.4

Effect of Cylindrical Length and Underflow Length on Separation
Dc=3.0 di/Dc=.15 do=.078 du/Dc=.33 alpha=3
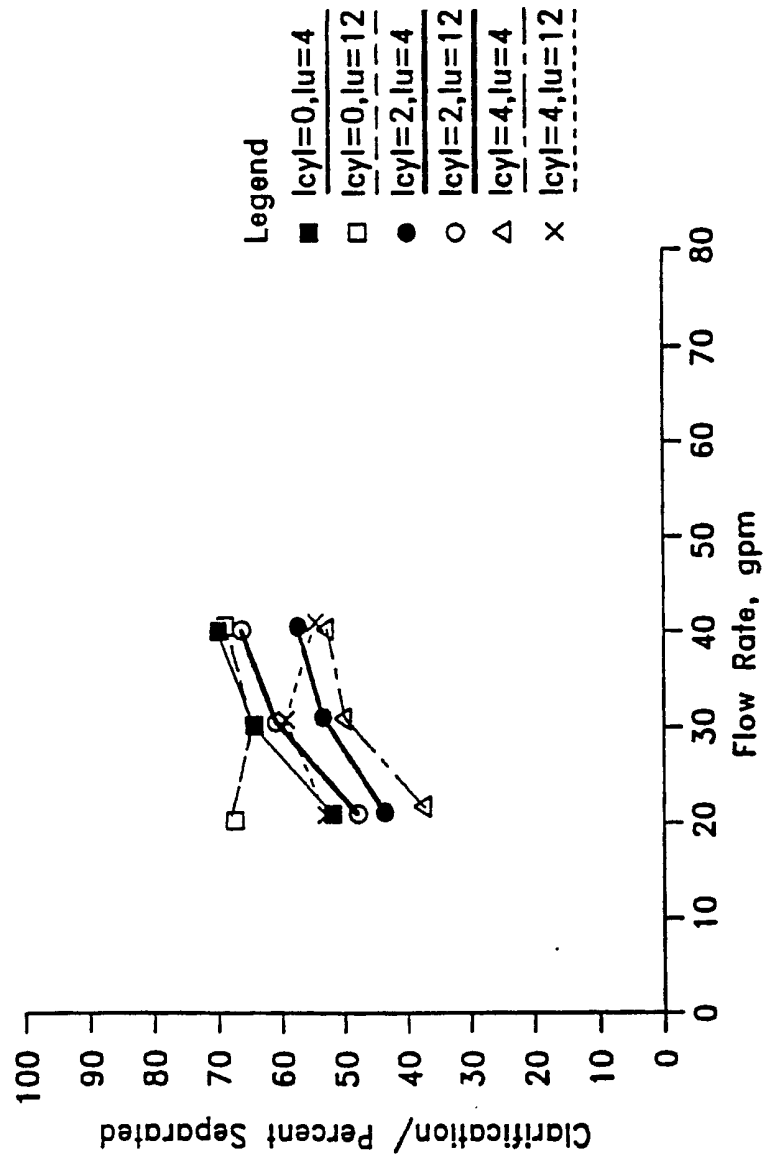
FIG.5

Effect of Underflow Length on Separation
Dc=3.0 di/Dc=.25 do=.078 du/Dc=.33 lcyl/Dc=2 alpha=6

Legend
lu/Dc=12
lu/Dc=18
lu/Dc=24

Flow Rate, gpm

Clarification/ Percent Separated
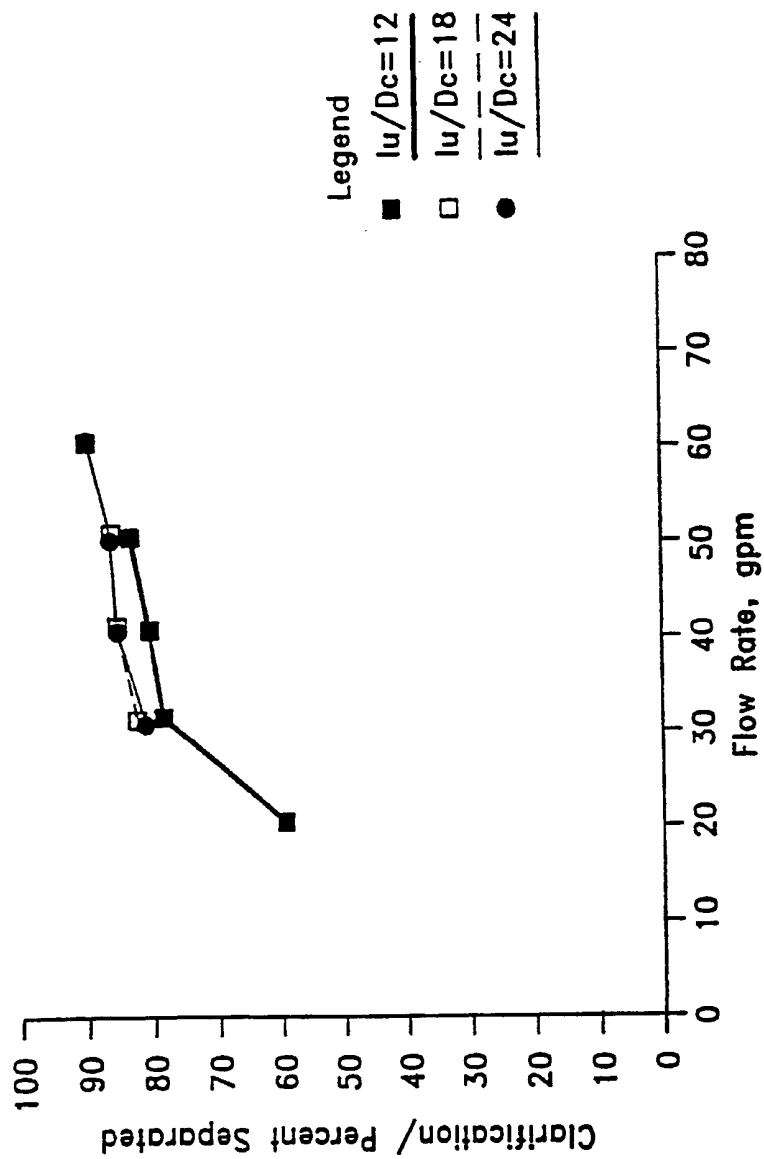
FIG.6

Vortoil Hydrocyclone

$\dfrac{di}{Dc} = .226$

$\alpha = 20°$

$\beta = 1\ 1/2°$

$\dfrac{do}{Dc} = \begin{matrix} .014 \\ .028 \\ .042 \end{matrix}$
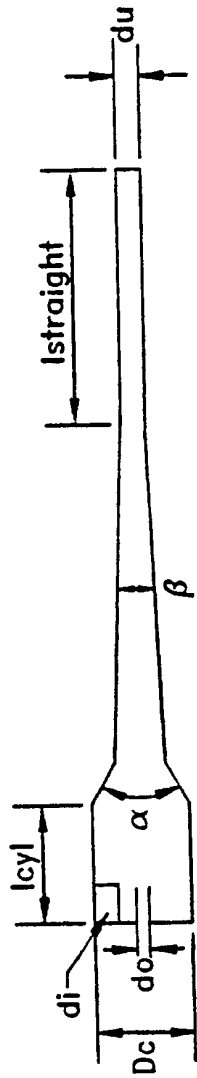
$du = 1$ in.

$Dc = 2.75$

$\dfrac{lcyl}{Dc} = 1$

$\dfrac{lstraight}{Dc} = 13$

FIG.7

FIG.8

5

HYDROCYCLONE SEPARATOR

10

The present invention relates to hydrocyclone separators used for separating two fluid phases and, more particularly, to hydrocyclone separators having specific component size ratios to improve oil from water separation

15 efficiency.

Numerous designs of hydrocyclone separators have been developed and utilized in the production of hydrocarbons from subterranean formations. Hydrocyclone separa-
20 tors are being utilized in more applications in hydrocarbon production due to increased environmental concerns regarding the d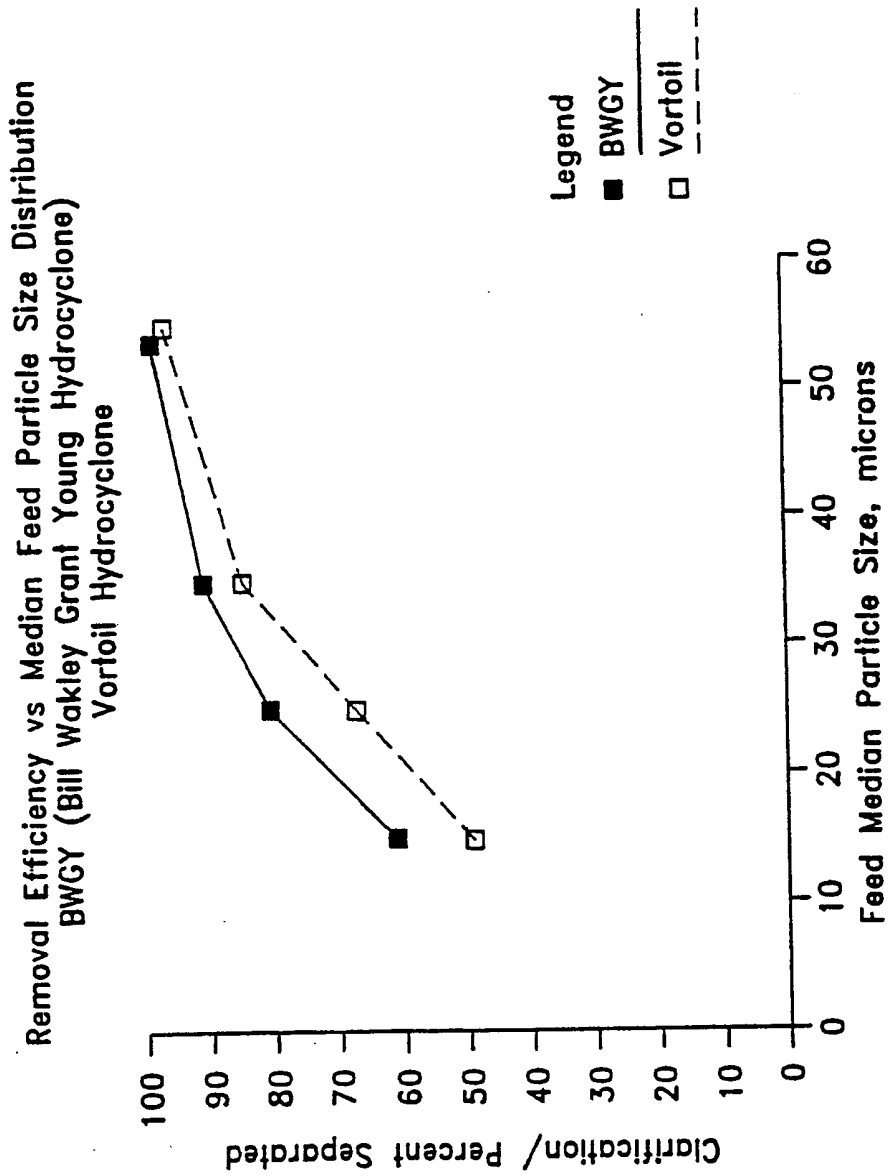ischarge of oil with produced water into bodies of water. Various government regulations have placed severe restrictions on the quantity of oil to be
25 discharged into the ocean, for example, in the North Sea, the discharge limit of oil with produced water currently is 48 mg/l. In order to meet such stringent oil discharge requirements, more efficient hydrocyclone separator designs need to be developed. Numerous research entities have conducted tests to find criticalities of the ratios

of components sizing to produce more efficient hydrocy-

clone separators. Examples of hydrocyclone separators

with critical design ratios are disclosed in the following

5 patents: US Patent 4,237,006, US 4,251,368, US 4,544,486,

US 4,576,724, US 4,464,264 and US 4,683,061.

The above-described patents disclose hydrocy-

clone separators that are useful for separation of small

quantities of oil from large streams of discharged water;

10 however, it has been found that hydrocyclone separators

made in accordance with one or more of these patents

require multiple angles and multiple cylindrical portions

which add to the complexity of manufacture of the hydrocy-

clone separator and thus increase the cost. Further,

15 there is a need for a hydrocyclone separator design which

has improved separation efficiency to meet the ever

increasing governmental environmental regulations.

The present invention has been developed to

20 overcome the foregoing deficiencies and meet the above

described needs. One embodiment of a hydrocyclone separa-

tor of the present invention has a substantially cylindri-

cal first portion with a central overflow outlet and at

least one tangential flow inlet adjacent a first end ther-

25 eof. The cylindrical first portion converges into a con-

ical second portion which in turn converges into a

substantially cylindrical third portion, which has a cen-

tral underflow outlet at an opposite end.

Through experimentation, it has been found that

if a hydrocyclone separator is designed to have a config-

uration within the ranges described herein, it can be

easily and inexpensively constructed, and it will exhibit

oil from water separation efficiency exceeding that of the

5 hydrocyclone separators currently available on the commer-

cial market.

The desired configuration of the hydrocyclone

separator is as follows:

$$do < du < Dc$$

$$.1 \leq di/Dc \leq .4$$

10

$$.01 \leq do/Dc \leq .06$$

$$0 \leq Lc/Dc \cong 2.0$$

$$3 \leq \alpha \leq 30$$

$$.1 \leq du/Dc \leq .5$$

$$9 \leq Ls/Dc.$$

15

The internal diameter of the cylindrical first portion is

Dc, the diameter of a circle which has the same area as

the flow inlet, regardless of shape, is di, the internal

20 diameter of the overflow outlet is do, the internal length

of the cylindrical first portion is Lc, the cone angle of

the second portion is α, the internal length of the cylin-

drical third portion is Ls, and the internal diameter of

the underflow outlet is du.

25 The invention is described by way of example with reference

to the accompanying drawings, in which:-

Figure 1 is a cross-sectional side view of a hydrocyclone

separator designed in accordance with the present invention.

Figure 2 is a three-axis graph showing oil separation

effeciency of a hydrocyclone separator of the pres-

ent invention versus changes in flow rate and inlet

diameter (di).

5   Figure 3 is a graph showing oil separation effi-
ciency of a hydrocyclone separator of the present
invention versus changes in the cone angle (α) and flow
rate.

Figure 4 is a graph showing oil separation effi-
ciency of a hydrocyclone separator of the present
10 invention versus changes in the underflow outlet (du)
size.

Figure 5 is a graph showing oil separation effi-
ciency of a hydrocyclone separator of the present
invention versus changes in the first portion's length
15 (Lc) and third portion's length (Ls).

Figure 6 is a graph showing oil separation effi-
ciency of a hydrocyclone separator of the present
invention versus changes in the third portion's length
(Ls).

20   Figure 7 is a cross-sectional side view of a
commercially available hydrocyclone separator, and its
design ratios.

Figure 8 is a graph showing oil separation effi-
ciency versus mean oil droplet size distribution for a
25 hydrocyclone separator of the present invention and for
the commercially-available hydrocyclone separator of
Figure 7.

In the utilization of hydrocyclone separators,
the engineer is usually given the produced oil concen-

tration and the oil/water stream's production flow rate.
From that point, the engineer determines the size and
number of hydrocyclone separators needed to achieve maxi-

5 mum oil separation efficiency. In an offshore platform
environment, the flow rates per hydrocyclone are usually
between about 10 and about 100 gpm (gallons-per-minute).
For the purposes of the following discussion, the perform-
ance of the hydrocyclone separators of the present

10 invention will be described in relation to this range of
flow rates. However, it should be understood that flow
rates less than or greater than this range can easily be
accommodated.

As shown in Figure 1, a hydrocyclone separator

15 of the present invention can include a substantially
cylindrical first portion 10 having a central overflow
outlet 12 at a first end thereof, and has at least one
tangential flow inlet 14 adjacent the first end thereof.
A second end of the substantially cylindrical first por-

20 tion 19 converges into a conical second portion 16 which
in turn converges into a substantially cylindrical third
portion 18, which has a central, oppositely located under-
flow outlet 20. The cylindrical first portion 10 is not
always necessary, and the overflow outlet 12 and flow inlet(s) 14

25 can be provided in the conical second portion 16, as is
well known. The hydrocyclone separator can be assembled
from multiple separate parts that are bolted, clamped,
welded, braised, glued together or the like to form a
single hydrocyclone separator. Preferably, the hydrocy-
clone separator is molded as a single unit from PVC,

polyurethane or other similar material. Further, the
hydrocyclone separator can be a rigid, self-supporting
unit or can be contained within a substantially cylindri-
5 cal shell (not shown) for protection of the molded compo-
nents.

For ease of understanding of the relationships
between the various components and sizing, the following
labels are used. The internal diameter of the cylindrical
10 first portion 10 is labeled Dc, the diameter of a circle
having the same area as the flow inlet(s), regardless of
shape, is labeled di, the internal diameter of the over-
flow outlet 12 is labeled do, the internal length of the
cylindrical first portion 10 is labeled Lc, the cone angle
15 of the conical second portion 16 is labeled α, the inter-
nal length of the cylindrical third portion 18 is labeled
Ls, and the internal diameter of the underflow outlet 20
is labeled du.

The at least one tangential flow inlet 14 intro-
20 duces the oil and water stream into the cylindrical first
portion 10 or in the conical second portion 16 in a manner
such that the stream will start to spiral immediately.
One tangential flow inlet 14 can be utilized; however, a
plurality of tangential flow inlets 14 can be utilized in
25 the same plane or in spaced relationship, as is desired.
The flow inlet(s) 14 can have an elongated shape, such as
a rectangle, oval or the like and the entry can be tangen-
tial or involute. The diameter (di) of the at least one
tangential flow inlet 14 is sized for the desired flow
rate in that a relatively larger diameter can handle

higher flow rates; the smaller the diameter (di) means a decrease in flow rate capability, but it has been found that for smaller inlet sizes (di) the separation effi-

5 ciency drops dramatically, as shown in Figure 2.

The diameter of the cylindrical first portion 10 (Dc) should be small relative to the overall length of the hydrocyclone separator because with less surface area, higher spin velocities can be obtained to increase sepa-

10 ration efficiency. If a relatively larger diameter (Dc) is utilized, it has been found that the separation effi- ciency drops dramatically.

The cylindrical first portion 10 can have an internal cone angle or taper the same as or less than the

15 cone angle α. For the purposes of the embodiment of the present invention, it is assumed that the cylindrical first portion 10 is preferably in the form of a right cyl- inder (0° taper). Further, it has been found that the length (Lc) of the cylindrical first portion 10 should be

20 as short as possible because little separation actually occurs within the cylindrical first portion 10 and it is beneficial to reduce the frictional drag caused by its surface area. In fact, the cylindrical first portion 10 can be eliminated so that the inlet 14 is within the con-

25 ical second portion 16. The ratios of Lc/Dc from 0 to approximately equal to 2.0 have been found to provide effective separation efficiency.

Figure 2 shows the results of testing the effect of varying inlet diameter (di) for various flow rates. A hydrocyclone separator was constructed with Dc=3.0",

$Lc/Dc=1$, $Ls/Dc=18$ and $\alpha=6°$. From 30 gpm to 70 gpm of

water at 60°F with 1,600 mg/liter of Bumpass crude oil,

having a median size of 25 microns, was passed through the

5 hydrocyclone separator and the ratio di/Dc was varied from

about 0.15 to about 0.35. From the graph shown in

Figure 2, a separation efficiency of 70+% was achieved

with $0.23 \leq di/Dc \leq 0.35$ for flow rates from about 50 gpm

to about 65 gpm. The best separation efficiency 75+% was

10 achieved with $0.24 \leq di/Dc \leq 0.28$ for flow rates from

about 55 gpm to about 63 gpm.

The central overflow outlet 12 is usually a

cylindrical opening in an upper panel 22 of the cylindri-

cal first portion 10 or it can include what is commonly

15 referred to as an oil-finding tube (vortex finder) 24

which extends part way into and coaxial with the cylindri-

cal first portion 10. The diameter (do) of the oil-find-

ing tube 24 and/or the opening 12 determines the flow

split for a given backpressure of fluid (i.e., how much

20 water comes with tne separated oil). The smaller the

diameter of the outlet 12 the less maximum amount of oil

or separated gas is permitted to pass out from the over-

flow of the hydrocyclone separator. The larger the diam-

eter of the overflow outlet 12, the greater the maximum

25 amount of oil is removed. When less than the maximum

amount of oil is separated out the overflow, water dis-

charges out the overflow to replace the oil. For most

applications, the ratio $.1 \leq di/Dc \leq .4$ has been found to

be satisfactory with $.24 \leq di/Dc \leq .28$ being preferred.

For most oil field applications with flow rates of between

about 30 gpm to about 70 gpm and from about 2" to about 4"
Dc, the overflow outlet diameter (do) can be from about
.014" to about .05".

5   The flow of fluid exiting the first portion 10
enters the conical second portion 16 where the cone angle
(α) causes the fluid to spin more rapidly. The spin
velocity increase results in greater forces on the oil
droplets resulting in the droplets moving to the center
10 and a separation being made. The transition from the
first portion 10 to the second portion 16 can be an abrupt
change from a cylinder to a cone if turbulence is mini-
mized or the transition can be through a gradual slope
change or curved/taper to facilitate the smooth spiralling
15 flow of the fluid into and through the conical second por-
tion 16. Through experimentation, it has been found that
a substantially single cone angle throughout the entire
length of the conical second portion 16 produces a prefer-
able, relatively higher separation efficiency. Thus,
20 there is no need for multiple angles, steps, and the like
as preferred by the prior hydrocyclone separators. It is
important that the angle (α) be chosen so that the transi-
tion from cylindrical to conical (and back to cylindrical
for entry into the third portion 18) obtains a satisfac-
25 tory momentum transfer to increase the rotational speed of
the introduced fluid and at the same time <u>minimize</u> the
surface area. Thus, a relatively larger angle is desired
in that it minimizes surface area; however, too large of
an angle will not effect a smooth momentum transfer.
While a relatively smaller angle does provide better sepa-

ration efficiency, too small of an angle causes the sepa-
ration efficiency to drop off dramatically at higher flow
rates because of the increase in surface area, thus caus-
5 ing drag and reduction of momentum.

The cone angle (α) can vary from about 0° to
about 2° across the length of the conical second
portion 16, but again, an essentially straight conical
section is desired for ease of manufacture and as will be
10 seen later better separation efficiency. Figure 3 shows
the effect of changes in flow rate (gpm) and cone angle
(α) on separation efficiency. Five hydrocyclone separa-
tors having $\alpha=1.5°$, 3°, 6°, 9.5° and 20° were built with
$Dc=30"$, $di/Dc=.25$, $do=.078"$, $du/Dc=.33$, $Lc/Dc=2$ and
15 $Ls/Dc=12$. The same fluid stream as used in the exper-
iments of Figure 2 was passed through the hydrocyclone
separators at from about 20 gpm to about 60 gpm. From the
results shown in Figure 3, the greater the cone angle (α),
the separation efficiency tends to peak for lower flow
20 rates then drop off dramatically. More specifically, the
single optimum cone angle (α) is approximately equal to
6°. This cone angle ($\alpha\cong6°$) appears to provide the best
balance of spin velocity and surface area for the usual
ranges of flow rate (gpm). However, cone angles (α) from
25 about 3° to about 30° are preferred.

The substantially cylindrical third portion 18
is connected to or is formed part of the convergence with
the second portion 16. It can have a slight internal
angle of from about 0° to about 3°, but it is preferred
that it will be in the form of a right cylinder (0° of

taper). Further, the third portion 18 can include a bend
or a curve to facilitate space saving in a particular
implementation. However, it has been found, again, that
5 maximum separation efficiency occurs when the cylindrical
third portion 18 is in the form of a straight right cylin-
der.

Through various experiments, the length (Ls) of
the cylindrical third portion 18 has been found to be very
10 important in improving the separation efficiency. Too
short of a third portion 18 reduces the separation effi-
ciency because the fluid is spiralling as it enters the
third portion 18 and if a longer third portion 18 is
included, additional separation can occur therein before
15 the spiraling motion dissipates. Beyond a certain length,
no additional benefit occurs.

Further, the diameter (du) of the underflow
outlet 20 has been found to be important in relation to Dc
because if too large of an underflow outlet 20 diameter
20 (du) is used, then the spin velocity in this section is
reduced resulting in poorer separation. Further, it
should be understood that if the third portion 18 is in
the form of a cylinder (with no taper) than the diameter
(du) of the underflow outlet 20 will be the same as the
25 average internal diameter of the third portion 18. To
test the importance of du to Dc, four hydrocyclone separa-
tors were built with du/Dc=.25, .33, .42 and .50. The
other design parameters of the hydrocyclone separators
were Dc=3.0 in., di/Dc=.25, do=.078, Ls/Dc=12, Lc/Dc=2 and
α=6°. The same fluid stream used for the experiments of

Figure 2 was passed through the hydrocyclone separators at from about 30 gpm to about 70 gpm. The results shown in Figure 4 show that a smaller diameter third portion 18 is

5 desired to take advantage of the flow exiting the conical second portion 16. Through experiments, the ratios of $.1 \leq du/Dc \leq .5$ have been found to provide adequate separation efficiency; however, ratios of $.21 \leq du/Dc \leq .42$ have been found best over the given flow rates;

10 $du/Dc \cong .33$ has been found to provide the best separation efficiency at the highest flow rates. High flow rate separation is desirable because fewer cone units then need to be used for a given total fluid treatment rate.

The effects of changing the length (Ls) of the

15 third portion 18 with respect to the length (Lc) of the first portion 10 was investigated. Three hydrocyclone separators were assembled having Lc=0 in., 2 in. and 4 in. and two different third portions were attached to each with Ls=4 in. and 12 in. The other design ratios were as

20 follows Dc=3.0", di/Dc=.15, do=.078", du/Dc=.33 and $\alpha=3°$. The same fluid used in the experiments of Figure 2 was passed through the hydrocyclone separators and from about 20 gpm to about 40 gpm. The results shown in Figure 5 show that by comparing the same Lc to different Ls that

25 the length (Ls) has a very strong influence on separation efficiency as previously described.

The effects of changing the length (Ls) of the third portion 18 with respect to the diameter (Dc) of the first portion 10 was investigated. A hydrocyclone separator was assembled having Ls/Dc=12, 18 and 24 with the fol-

lowing other design ratios: Dc=3.0", di/Dc=.25, do=.078", du/Dc=.33, Lc/Dc=2 and α=6°. A fluid having a median size of 35 microns and an oil concentration of 1,000 mg/liter

5 was passed through the hydrocyclone separator at from about 20 gpm to about 70 gpm. The results shown in Figure 6 show that by merely increasing the length (Ls) of the third portion 18 on a 3 in. diameter cylinder from 36 in. to 72 in. that a separation efficiency of over 90%

10 is achieved. It has been found that 9 ≤ Ls/Dc provides satisfactory results; preferably Ls/Dc is from about 9 to about 27 and most preferably from about 12 to about 24. Tests have shown that for Dc equal to about 3 in., a length (Ls) of the third portion 18 above about 54 in.

15 does not provide any additional separation benefit.

Tests were conducted to prove that the separation efficiency of a hydrocyclone separator made in accordance with the above-described ratios could have equal or exceed the oil separation efficiency of the best

20 commercially available unit. A hydrocyclone manufactured and marketed by BWM Vortoil, Ltd., was purchased and measured to have the dimensions shown in Figure 7.

One will note that several of the ratios of the hydrocyclone separator shown in Figure 7 are within the

25 possible ranges disclosed herein with regard to the hydrocyclone separator of the present invention. However, important differences were noted, specifically Ls was less than 36" for a 2.75" Dc and more importantly the hydrocyclone separator had two angled portions, one of 20° and a second of 1.5°, thereby increasing the surface area.

A hydrocyclone separator made in accordance with the present invention was assembled and had the following dimensions $D_c=3.0"$, $d_i/D_c=.25$, $d_o/D_c=.028$, $L_c/D_c=1$, $\alpha=6°$,

5 $d_u/D_c=.33$ and $L_s/D_c=18$. A fluid stream of water with 1,000 mg/liter of Bumpass crude oil was passed through both hydrocyclone separators. Both the commercial and the hydrocyclone separator of the present invention exhibited excellent separation efficiency for slurries which had a

10 median size of 55 microns achieving about 97.5% separation efficiency. However, as the oil droplet size decreased, the superior separation efficiency of the hydrocyclone separator of the present invention becomes obvious.

The inventors have found that a hydrocyclone

15 separator can be designed in accordance with the above-described ratios/dimensions and for the typical oil from water separation process at the flow rates typically encountered in the offshore or onshore production of oil/gas, that a superior separation efficiency can be

20 achieved.

Wherein the present invention has been described in particular relation to the drawings attached hereto, it should be understood that other and further modifications, apart from those shown or suggested herein, may be made

25 within the scope of the appended claims.

CLAIMS

1.   A hydrocyclone separator comprising:

a first portion having a central overflow outlet and having at least one tangential flow inlet and connecting into a conical second portion;

the conical second portion having essentially a single cone angle and converging at an end opposite the first portion into a substantially cylindrical third portion;

the substantially cylindrical third portion having a central underflow outlet at an end opposite the conical second portion;

the internal diameter of the first portion being Dc, the diameter of a circle having the same area as the at least one tangential flow inlet, regardless of shape, being di, the internal diameter of the central overflow outlet being do, the internal length of the first portion being Lc, where Lc may be zero, the cone angle of the conical second portion being α, the internal length of the cylindrical third portion being Ls, and the internal diameter of the underflow outlet being du; and

the configuration of the hydrocyclone separator being in accordance with the following relationships:

$$do < du < Dc$$
$$.1 \le di/Dc \le .4$$
$$.01 \le do/Dc \le .06$$
$$0 \le Lc/Dc \le 2.0$$
$$3^{\circ} \le \alpha \le 30^{\circ}$$
$$.1 \le du/Dc \le .5$$
$$9 \le Ls/Dc.$$

2.   A hydrocyclone separator according to Claim 1, wherein the first portion is susbstantially cylindrical and wherein the central overflow outlet is positioned at a first and thereof remote from the conical second portion and wherein the tangential flow outlet is positioned adjacent said first end.

3.   A hydrocyclone separator according to Claim 1 or Claim 2, wherein the substantially cylindrical third portion is in the form of a right cylinder.

4.   A hydrocyclone separator according to any of the preceeding claims, wherein $0.23 \leq di/DC \leq 0.35$.

5.   A hydrocyclone separator according to Claim 4, wherein $0.24 \leq di/DC \leq 0.28$.

6.   A hydrocyclone separator according to any of the preceding claims, wherein $.014 \leq do \leq .05$.

7.   A hydrocyclone separator according to any of the preceding claims, wherein $\alpha \approx 6^{\circ}$.

8.   A hydrocyclone separator according to any of the preceding claims, wherein $.21 \leq du/Dc \leq .42$.

9.   A hydrocyclone separator according to any of the preceding claims, wherein Ls/Dc is between about 9 and about 27.

10.   A hydrocyclone separator according to Claim 9, wherein Ls/Dc is between about 12 and about 24.

11.   A hydrocyclone separator according to any of the preceding claims, wherein the substantially cylindrical first portion is in the form of a right cylinder.

12.   A hydrocyclone separator substantially in accordance with any example of the invention herein described with reference to Figure 1.